Fluids

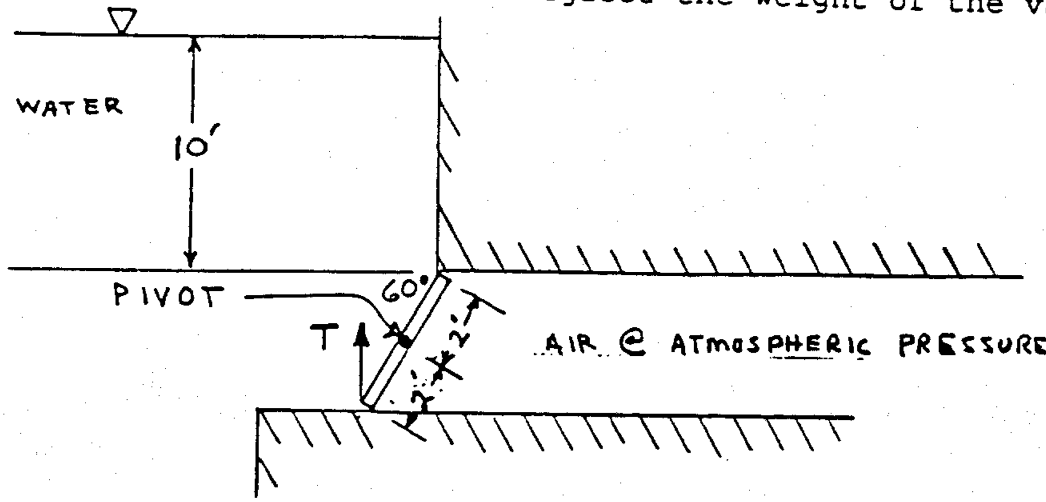
Gary Crossman
gcrossma@odu.edu

Mechanical PE Review

Center for Continuing Engineering Education (C2E2)

Professional Engineers Exam
Review Course Problems

1. The 4′x 4′ gate shown is acting as a valve. When the water level above the top of the gate is 10 ft. find the force T needed to open the valve. Neglect the weight of the valve.



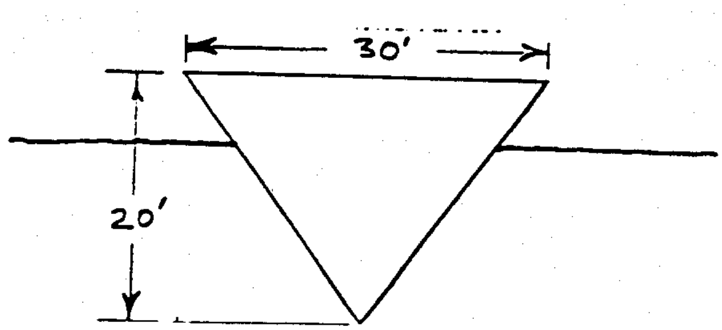
2. An empty, horizontal, rectangular, 8 ft. wide, 6 ft. high, 10,000 gallon fuel oil tank with a weight of 8340# is placed in an open excavation on a coarse gravel bed such that the top of the tank is 6 ft. below ground level.

   (a) A sudden rainstorm starts to fill the open excavation with water. To what height in feet above the bottom of the tank can the water rise before the empty tank will float?.

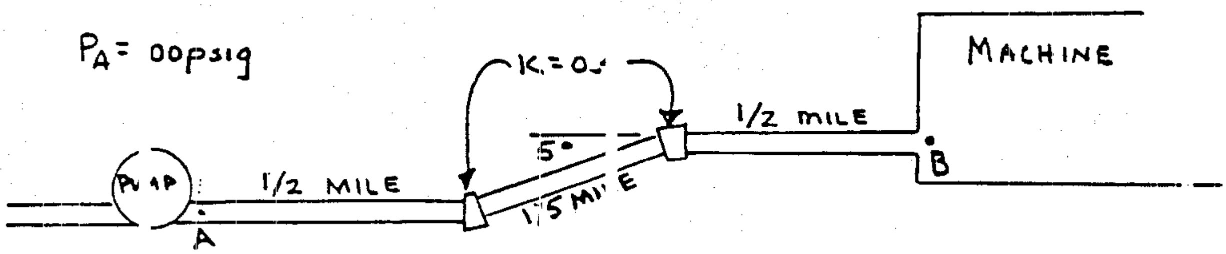
   (b) Fuel tanks of this type are sometimes anchored down by steel straps over the tank tied to a concrete mat poured in the excavation before the tank is lowered in place. How many cubic yards of concrete would be required in this case to keep the empty tank from floating if completely submerged? Concrete weight 150#/cu. ft.

   (c) If the tank is full of kerosene (density 50 lb. per cu. ft.) and completely submerged in water, would a concrete anchor be required to prevent floating of the tank? If so, how many cubic yards of concrete?

3. A triangular shaped vessel as shown loaded weighs 400 tons, is 60 ft. long and has its center of gravity located 13′ up the triangle. It is afloat in sea water (γ = $64 lbf/ft^3$). Is the vessel stable in the loaded condition?



4. A pump moves 1.0 cu. ft./sec. of water thru a 6" pipeline as shown. P_A = 100 psig. Assume that the pipe is new commercial steel throughout and for water $\nu = 0.1217 \times 10^{-4}$ ft.^{2}/sec. What is the pressure at "B" in psi entering the machine?



5. Water is being pumped from a deep well through a 10 inch I.D. cast iron pipe line 1000 feet long from pump discharge into an elevated tank whose water surface is at elevation +300 feet. When the pump is operating continuously, the water surface in the well draws down to elevation +175 feet. A pressure gage located at the pump discharge at elevation +200 feet indicates a pressure of 58 psi. Neglect minor losses.

Required: a. Determine the pump discharge in gallons per minute.

b. Using a combined efficiency of 65 per cent, for the pump and motor, determine the monthly cost of pumping if the average pumping time is 6 hours per day, and electric energy is available at $0.06 per Kwh.

6. Glycerin at 50°F is being pumped at the rate of 2,500 gal/min through a flow system which consists of 1,500 feet of 4 inch schedule 40 commercial steel pipe.

It has been suggested that heating the oil to 100°F would result in a more efficient operation. Assuming that electrical energy would be used for pumping or heating, determine which of these conditions would be the most economical.

Temperature	Viscosity	Sp. Gr.
50°F	4000×10^{-5} lb-sec/ft^2	1.26
100°F	500×10^{-5} lb-sec/ft^2	1.20

7. The Department of Energy indicates that a considerable amount of residential/farm power could be obtained from small hydroelectric installations. Such a system might consist of the following:

3

A water pond/dam arrangement in which the water level is maintained at an elevation of 3870 feet. From a water intake located 10.0 feet below the pond surface, a 350 foot long, 6 inch Sch 40, galvanized iron pipe leads to the turbine/generator unit which is situated at an elevation of 3780 feet. The discharge pipe (of the same type as the intake pipe) from the turbine is 2050 feet long and discharges into the air at an elevation of 3750 feet. A control valve in the discharge line is set to permit a flow of 58.0 ft^3/min at a water temperature of 60°F when the pipe is running full. Turbine/generator efficiency is 86%. Fitting and exit/entrance losses amount to 815 equivalent pipe diameters.

REQUIREMENTS:

(a) Determine the total frictional loss per pound mass of fluid.

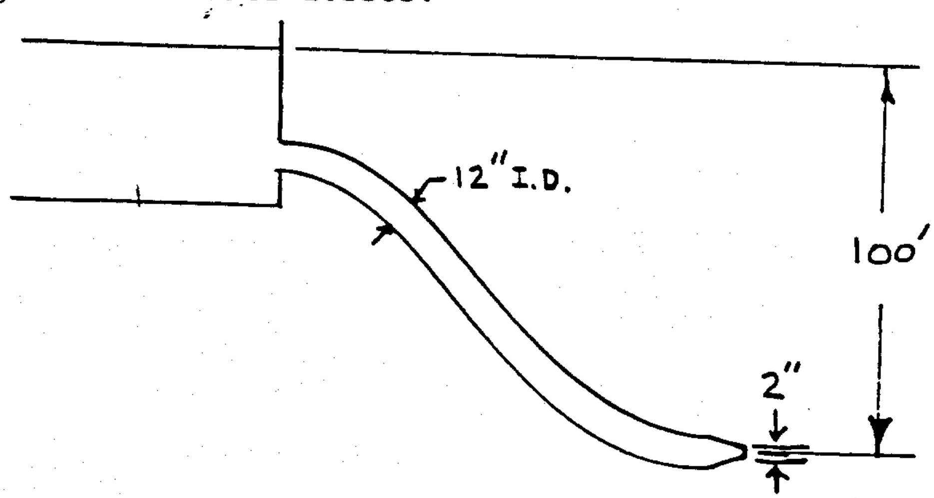
(b) Determine the shaft work per pound mass of fluid.

(c) Determine the number of 100 W light bulbs that could be lit by this system.

8. An existing storage tank is available for use as a feed reservoir for a new process. It is possible to use the old 1-in. Schedule 40 line already in place, provided 25 gpm flow can be obtained. The fluid is linseed oil (viscosity = 15 c.p., specific gravity = 0.92). The tank bottom is 30 ft. above the discharge point (open pipe on discharge). The line contains 65 ft. of straight pipe, 3-90° elbows, 1 gate valve, and 1 globe valve. Will the existing line be adequate? Assume pipe is wrought iron.

9. A cast-iron pipe line, 12 inches inside diameter and 10,000 feet long, leading from a reservoir, terminates in a nozzle of 2-inch diameter, discharging into the atmosphere. The center of this nozzle is 100 feet below the free surface of the water in the reservoir supplying the pipe line.

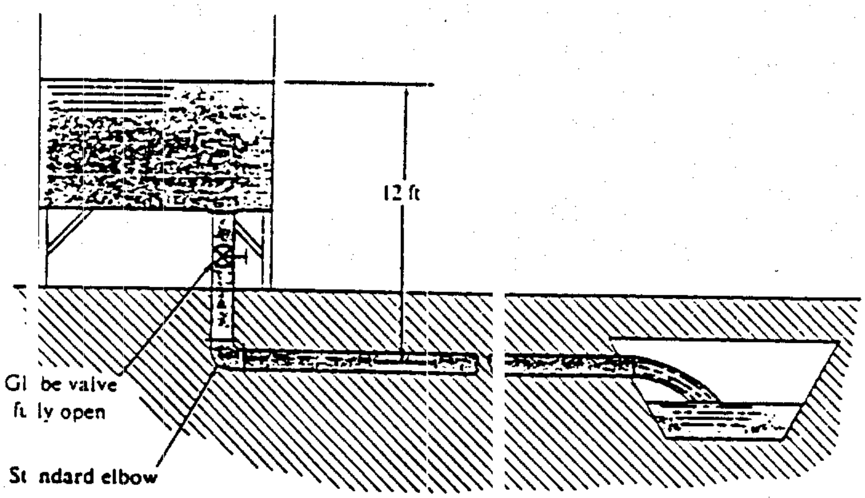
Find the volume flow rate, cfs, and the power in the jet. Neglect all minor losses.



10. A water line is planned to connect a new reservoir to an existing water treatment plant. The average water surface elevation of the reservoir is 900' msl. The elevation of the inlet works of the treatment plant 7 miles ~~for~~ from the reservoir is 750 msl. It is anticipated that only concrete pipe will be available and that there should be included in the line two (2) gate valves, a check valve and four (4) 90° bends to provide flexible routing. The projected peak day demand is 12 million gallons.

Determine the pipe diameter considering that concrete pipe is available in a range of diameters from 12" to 48" in 6" increments.

11. The tank shown below is to be drained to a sewer. Determine the size of new Schedule 40 pipe which will carry at least 400 gpm of 80°F water through the system shown. The total length of pipe is 75 ft.

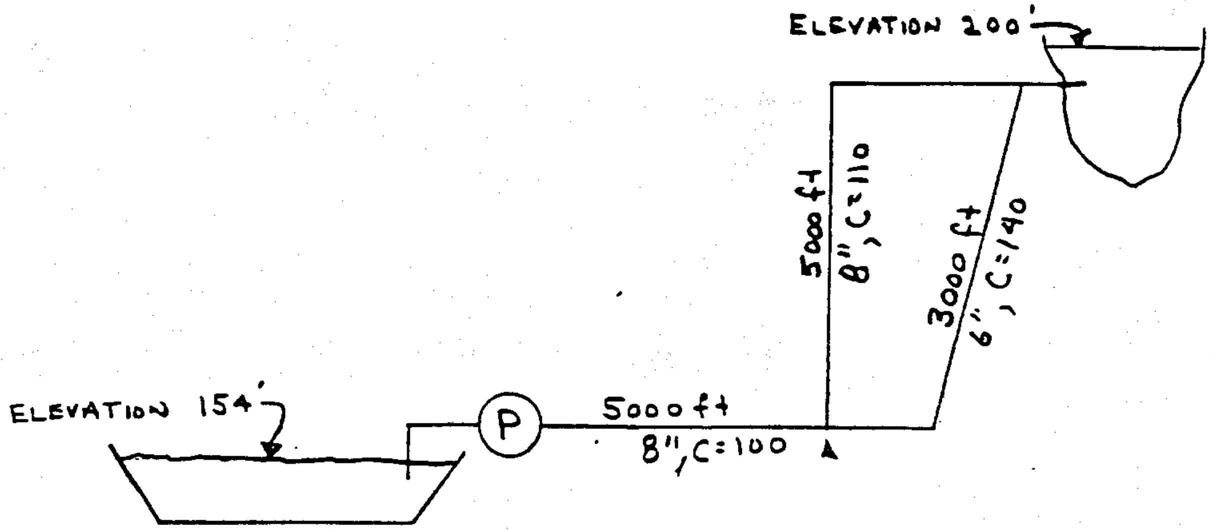


12. 4 GPM of SAE lube oil at 100°F (viscosity, μ = 480 centipoise, sp gr = 0.9) is pumped thru 2.5 miles of 3 in. schedule 40 pipe to an outlying process building. The flow rate must be increased to 6 GPM to meet new process requirements. Since the existing line cannot be removed from service for an extended period, a parallel branch of the same size pipe will be added and then wet-tapped to the existing line. How long must the parallel branch be to provide the increased out flow? (Neglect the pressure drop caused by the wet-tap connection.)

6

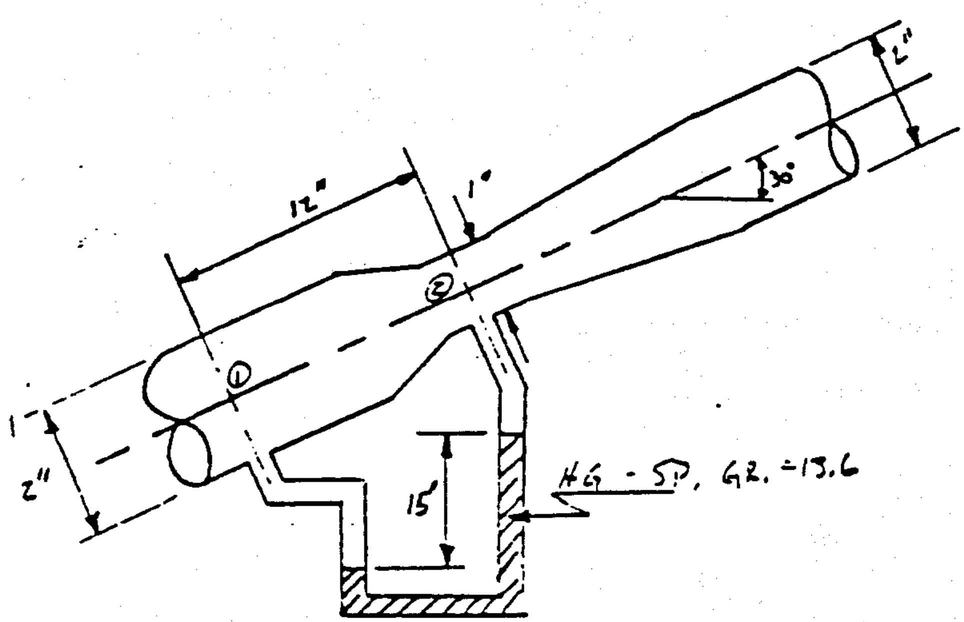
13. In the below pump problem, it is desired to pump 900,000 gallons per day of water from a stream to a pool as shown above. If the combined pump and motor efficiency is 68%, answer the following:

1. What is the total pumping head?
2. What is the horsepower requirement?



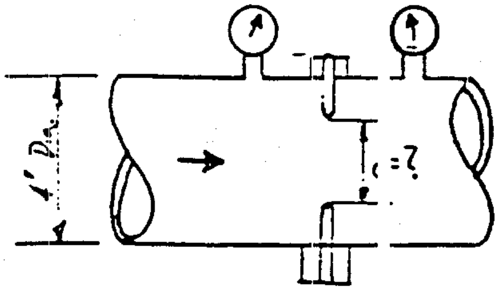
14. It is necessary to supply 250 standard cubic feet per second of natural gas (CH_4) at 60 psig and 70°F. The gas must travel through a 12-inch Dia. (inside) pipe which is 3 miles long. Calculate the required pressure at the reservoir. (Assume the gas to be incompressible for the purpose of this problem).

15. How many gallons per minute (gpm) of gasoline (sp. gr. = 0.80) are flowing through the 2" x 1" venturi meter shown. C_v = 0.97.

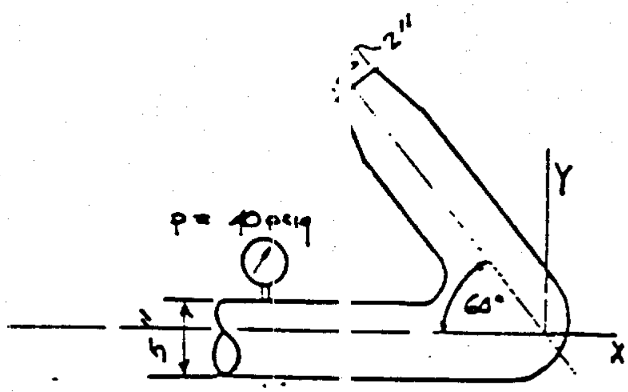


6

16. A sharp-edged concentric orifice is to be placed between the flanges in a horizontal pipeline to measure the flow; the pressure drop across the orifice is limited to 1% of the static pressure on the line. The pipeline is to carry boiler feedwater that is being pumped into the boiler through a 4-inch. diameter pipe @220°F and [illegible]00 psig at the rate of 50,000 lb/hr. Determine the diameter of the orifice, in inches.



17. Water flowing in the bend discharges into the atmosphere through the 2-inch nozzle. The bend lies in a horizontal plane. Determine the resultant of the force the water exerts on the bend. Neglect all losses.



18. A pump is to deliver 350 gpm of hot water. The pump is to receive suction through a 6-inch schedule-40 pipe from a tank elevated above the pump. The water is to be saturated liquid at 250 psig. A net positive suction heat (NPSH) of 75 feet is recommended for these operating conditions. Pipe friction loss will average 1.0 foot for each 20 feet of height.

Determine the minimum water level elevation above the pump center line to yield the specified NPSH.

19. A centrifugal pump is to be designed to pump water, at 180°F, at a rate of 200 gpm from a tank which is vented to the atmosphere. The outlet from the tank is located five feet above the pump. The pump suction line is 4" NPS, sch. 40 pipe which is 8 ft. long. This suction line contains 2 short radius 90° elbows. Calculate the net positive suction head that will be available to the pump when the water level is at the point of suction in the tank.

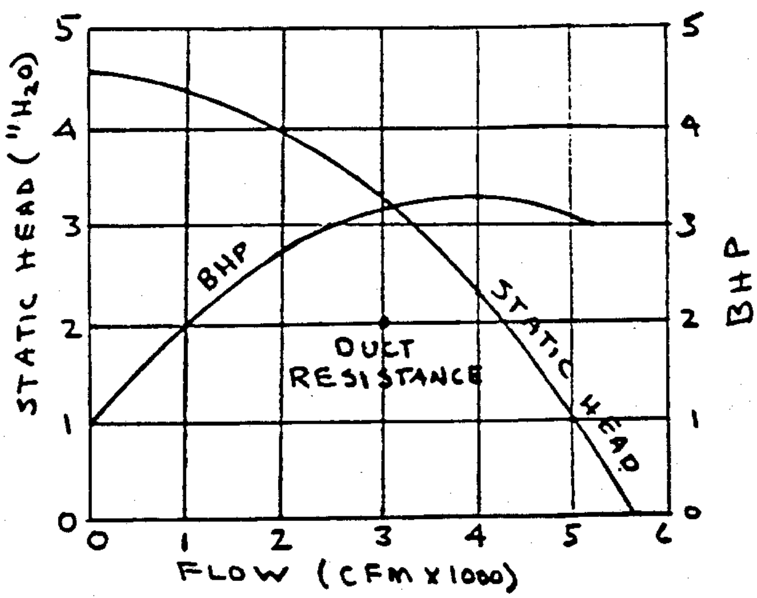
7

20. A double suction centrifugal pump rated at 1200 gpm and 140 ft. head at 1750 RPM is set 20 ft. below the water level in a tank in which water is maintained saturated at 70 psia the suction line consists of 80 ft. of straight 6" schedule 40 steel pipe, 3 medium radius elbows and 3 gate valves. When tested at 600 gpm the pump functioned satisfactorily, but when attempts were made to test at rated capacity the pump could not deliver. With this information, what system fault could you verify or disprove? Show calculations and assumptions to substantiate your conclusions.

21. A large centrifugal pump has a 10" diameter inlet and a 5" diameter discharge. The measured flow rate is 818 gal./min. The measured inlet pressure is 5" of Hg. above atmospheric and the discharge pressure, measured at a point 4 ft. above the pump inlet, is 30.7 psia. Pump input is 10 horsepower.

Find:
- a. The pump efficiency.
- b. The new flow rate, net head, and BHP if the pump speed is increased from 1750 RPM to 3500 RPM.

22.



A centrifugal fan operating at 1450 rpm has characteristics shown at left, and is connected to a duct system which by itself has a static resistance of 2.0 in. H_2O when handling 3000 cfm of std. air.

(a) At what flow, static pressure, and bhp will the fan and duct system operate when connected together?

(b) Assume that it is desirable to cause 5000 cfm of air to flow through the same fan and duct system by changing pulley ratios. What speed, static pressure, and bhp would be required to do this? (List assumptions necessary).

8

23. In cases where dry-bulk materials are being handled in an air stream or where they can be introduced into a vessel in an air stream, consideration should be given to the use of a venturi feeder. A venturi feeder is a simple device. It is low in cost, light in weight and can be fabricated by a sheet-metal shop.

The following data apply:

1. A venturi feeder as shown in the Figure below is to handle 600 pounds per hour of a light dry powder.
2. Use 50 standard cubic feet of air per pound of dry material.
3. Use an air velocity of 3,000 fpm at points (1) and (3).
4. Use a venturi width of 5 inches throughout its length.
5. A static pressure of 2.0 inches water gage (i.w.g) is required at deliver (point (3)).
6. A slight vacuum is needed at the venturi throat.

   Use $h_{s2} = -0.05\ i.w.g.$.

7. Venturi loss coefficients are as follows:

   Converging section, $K_C = \dfrac{h_{t1} - h_{t2}}{h_{v2} - h_{v1}} = 0.07$

   Diverging section, $K_D = \dfrac{h_{t2} - h_{t3}}{h_{v2} - h_{v3}} = 0.20$

   where: h_v = velocity head, i.w.g.
   h_s = static head, i.w.g.
   h_t = total head = $h_s + h_v$

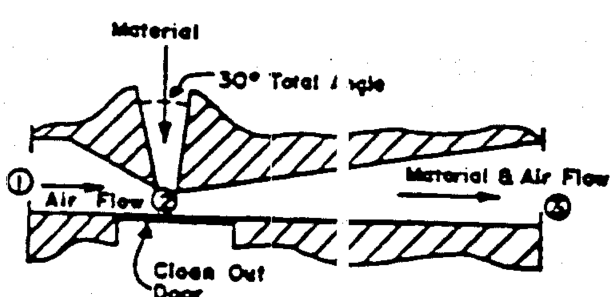
   Points (1), (2), (3) refer to illustration below.

   REQUIREMENTS:

   (a) Determine the required venturi height in inches, at points (1), (2), and (3).

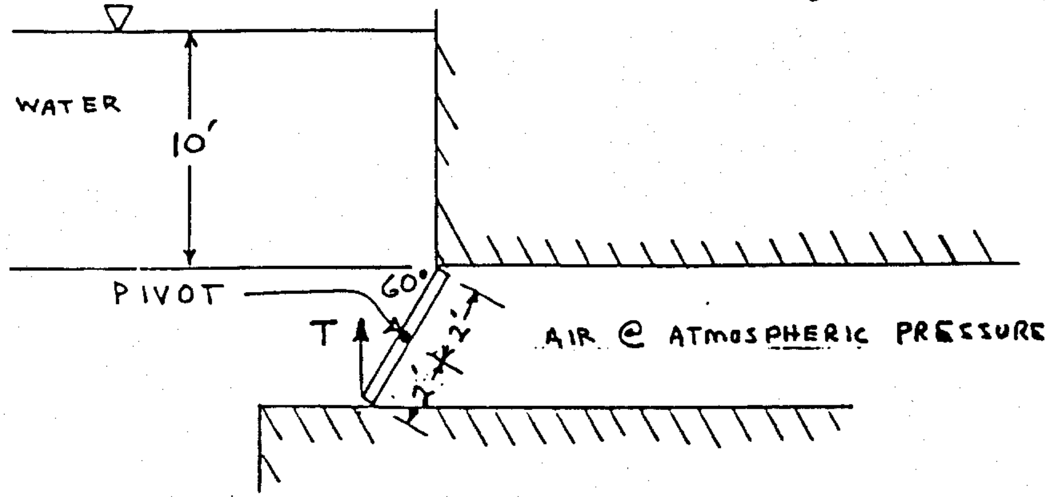
   (b) Determine the required total head, h_{t1} in i.w.g. at venturi entrance.

   (c) Determine the required fan air hp and brake hp. Assume a reasonable fan efficiency.



9

1. The 4'x 4' gate shown is acting as a valve. When the water level above the top of the gate is 10 ft. find the force T needed to open the valve. Neglect the weight of the valve.



Find Force of water on gate. Assume water at 70°F

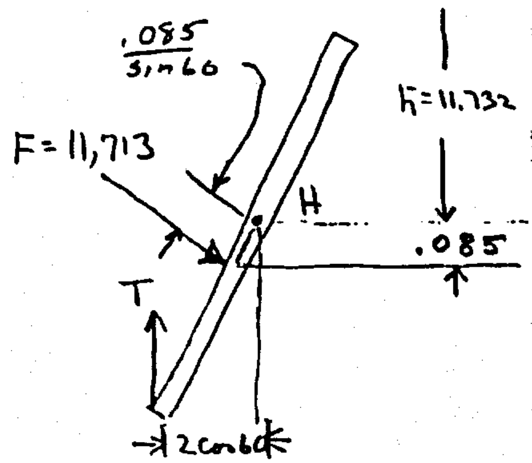
$F = \gamma \bar{h} A = (62.4)(10 + 2\sin 60)(4\times 4) = (62.4)(11.732)(16) = \underline{11{,}713\ lb}$

$h_p = \bar{h} + \dfrac{I_G \sin^2\theta}{\bar{h} A} = 11.732 + \dfrac{\frac{4^4}{12}(\sin^2 60)}{11.732(16)} = 11.732 + .085 = 11.817$

$\sum M_{Hinge} = T(2\cos 60) - F\left(\dfrac{.0853}{\sin 60}\right) = 0$

$T(1) = (11{,}713)(.0981)$

$\boxed{T = 1150\ lb_f}$



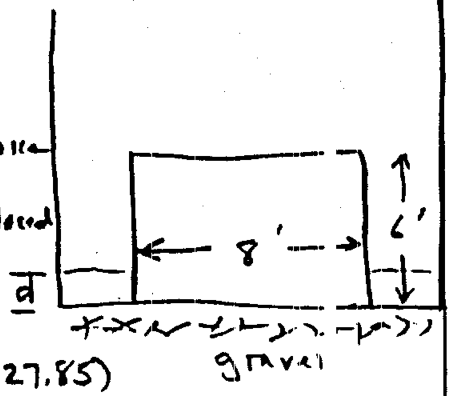
10

2. $W_T = 8340\ lbf$, $V_T = 10{,}000\ gal$, $w = 8\ ft$, $h = 6\ ft$

V_T

$$V_T = l \times w \times h, \quad l = \frac{V_T}{w \times h} = \frac{10{,}000\ gal \cdot 1\ ft^3/7.48\ gal}{8 \times 6\ ft^2} = \frac{1337\ ft^3}{48\ ft^2} = \underline{\underline{27.85\ ft}}$$

The gravel indicates that water can seep under the tank and no suction forces exist in the soil



a) $\Sigma F = W_T - F_B = 0$ $\quad F_B$ = buoyant force

$W_T = F_B = \gamma_w V_D$ $\quad V_D$ = Volume displaced

$W_T = \gamma_w (l \times w \times d)$

$d = W_T / (\gamma_w \times l \times w) = 8340 / (62.4 \times 8 \times 27.85)$

$\boxed{d = 0.6\ ft = 7.2''}$

b) Assume the concrete lies on top of the gravel bed, making it subject to buoyant forces also.

$$\Sigma F = W_T + W_c - F_{B_T} - F_{B_c} = 0$$

$$W_T + \gamma_c V_c - \gamma_w V_T - \gamma_w V_c = 0$$

$$V_c = \frac{\gamma_w V_T - W_T}{\gamma_c - \gamma_w} = \frac{(62.4)(1337) - 8340}{150 - 62.4} = 857\ ft^3 \cdot \frac{1}{27}$$

$\boxed{V_c = 31.75\ yds^3}$

c) $\Sigma F = W_T + W_K + W_c - F_{B_T} - F_{B_c} = 0$

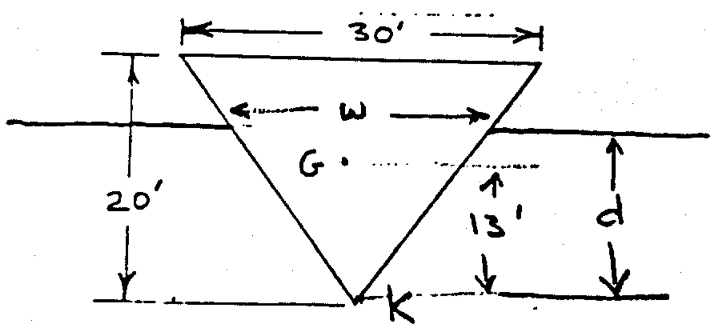
$$W_T + \gamma_K V_T + \gamma_c V_c - \gamma_w V_T - \gamma_w V_c = 0$$

$$V_c = \frac{\gamma_w V_T - W_T - \gamma_K V_T}{\gamma_c - \gamma_w} = \frac{(62.4)(1337) - 8340 - (50)(1337)}{150 - 62.4}$$

$V_c = 94\ ft^3 \cdot \frac{1}{27} = \boxed{3.48\ yd^3}$ $\quad \underline{\underline{yes}}$

11

3. A triangular shaped vessel as shown loaded weighs 400 tons, is 60 ft. long and has its center of gravity located 13' up the triangle. It is afloat in sea water ($\gamma = 64 lbf/ft^3$). Is the vessel stable in the loaded condition?



For stability G must be below the metacenter, M

or $KG < KM$

$KM = KB + BM$ B is at center of displaced volume.

$KB = 2/3\ d$

Use buoyancy equation to get d

$\sum F = 0 = W_T - F_B$, $W_T = F_B = \gamma_w V_D = \gamma_w (\frac{1}{2} w \times d)(l)$

but by similar triangles $\frac{w}{30} = \frac{d}{20}$, $w = 3/2\ d$

then $W_T = \gamma_w (\frac{1}{2} (\frac{3}{2} d)(d)(l) = 3/4\ d^2 (l)(\gamma)$

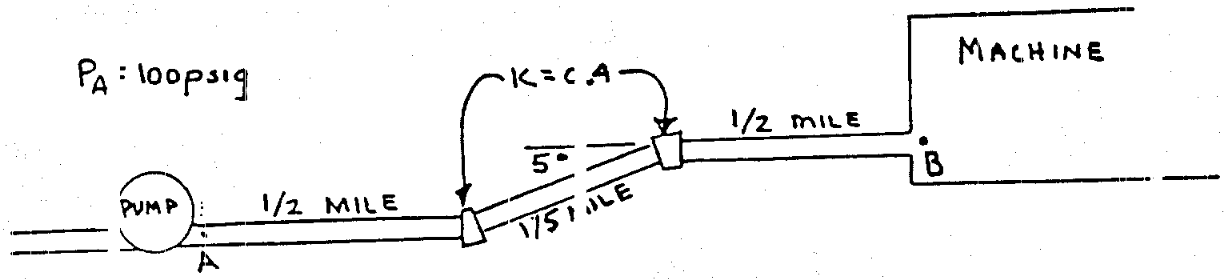
$d = \sqrt{\frac{4}{3} \frac{W_T}{l \times \gamma_w}} = \sqrt{\frac{4}{3} \frac{(400 \times 2000)}{60 \times 64.0}} = 16.67\ ft$, $w = 3/2 (16.67)$, $w = 25\ ft$

$KB = 2/3\ (16.67) = \underline{\underline{11.11}}\ ft$

$BM = \frac{I_s}{V_D} = \frac{60(25)^3/12}{\frac{1}{2}(60 \times 25 \times 16.67)} = \underline{\underline{6.25\ ft}}$

$KB = 11.11 + 6.25 = \boxed{17.36 > 13 (KG) \therefore \text{Stable}}$

4. A pump moves 1.0 cu. ft./sec. of water thru a 6" pipeline as shown. P_A = 100 psig. Assume that the pipe is new commercial steel throughout and for water $\nu = 0.1217 \times 10^{-4}$ ft.^{2}/sec. What is the pressure at "B" in psi entering the machine?



Write energy equation

$$\frac{P_A}{\gamma} + \cancel{\frac{V_A^2}{2g}} + Z_A = \frac{P_B}{\gamma} + \cancel{\frac{V_B^2}{2g}} + Z_B + h_f$$

$$P_B = P_A + \gamma\left[(Z_A - Z_B) - h_f\right]$$

$$P_B = 100 + \frac{62.4}{144}\left[\left(0 - \tfrac{1}{5}(5280)\sin 5^\circ\right) - h_f\right.$$

$$\underline{P_B = 100 - 39.9 - .433\,h_f}$$

$$P_B = 100 - 39.9 - .433(92.2)$$

$$P_B = 100 - 39.9 - 39.6$$

$$\boxed{P_B = 20.5 \text{ psig}}$$

$$V_A = V_B = Q/A$$

$$V = \frac{1.0\ \text{ft}^3/\text{s}}{\pi(6)^2/(4 \cdot 144)}$$

$$V = 5.09\ \text{ft/s}$$

$$h_f = \underbrace{\left(f\frac{L}{D}\frac{V^2}{2g}\right)}_{\text{pipe}} + \underbrace{\left(2K\frac{V^2}{2g}\right)}_{\text{elbows}}$$

for steel $\frac{\epsilon}{D} = \frac{.0002}{6/12} = .0004$

$$N_R = \frac{VD}{\nu} = \frac{(5.09)(.5)}{.1217 \times 10^{-4}} = 2.1 \times 10^5$$

from moody

$f = .018$

$$h_f = \left[(.018)\left(\frac{(1.2)(5280)}{.5}\right)\right]\frac{5.09^2}{64.4}$$

$$+\ 2(.4)\left(\frac{5.09^2}{64.4}\right)$$

$$h_f = 91.8 + \underset{\uparrow}{.3} = 92.2$$

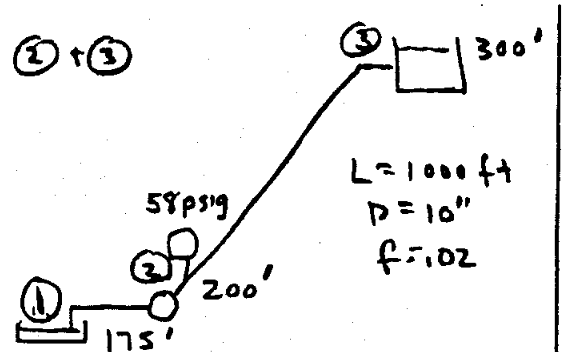
could neglect

5. Water is being pumped from a deep well through a 10 inch I.D. cast iron pipe line 1000 feet long from pump discharge into an elevated tank whose water surface is at elevation +300 feet. When the pump is operating continuously, the water surface in the well draws down to elevation +175 feet. A pressure gage located at the pump discharge at elevation +200 feet indicates a pressure of 58 psi. Neglect minor losses. Assume $f \doteq .02$.

Required: a. Determine the pump discharge in gallons per minute.

b. Using a combined efficiency of 65 per cent, for the pump and motor, determine the monthly cost of pumping if the average pumping time is 6 hours per day, and electric energy is available at $0.06 per Kwh.

a) Write Energy Equation between ② + ③



$$\frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 = \cancel{\frac{P_3}{\gamma}}^{0} + \cancel{\frac{V_3^2}{2g}}^{0} + z_3 + h_f$$

$$h_f + \frac{V_2^2}{2g} = \frac{P_2}{\gamma} + (z_2 - z_3)$$

$$f\frac{L}{D}\frac{V_2^2}{2g} - \frac{V_2^2}{2g} = \frac{58(144)}{62.4} + (200-300)$$

$$V_2 = \sqrt{\frac{2g(134-100)}{(f\frac{L}{D}-1)}} = \sqrt{\frac{64.4(34)}{\left[(.02)\left(\frac{1000}{10/12}\right)\right]-1}} = \underline{\underline{9.74\ ft/s}}$$

$$\dot{V} = AV = [\pi(10)^2/4(144)][9.74] = 5.31\ \frac{ft^3}{s} \cdot \frac{449\ gpm}{ft^3/s} = \boxed{2385\ gpm}$$

b) Need h_A + power. Write Energy Equation between ① + ③

$$\cancel{\frac{P_1}{\gamma}} + \cancel{\frac{V_1^2}{2g}}_{0} + z_1 + h_A = \cancel{\frac{P_3}{\gamma}} + \cancel{\frac{V_3^2}{2g}} + z_3 + h_f$$

. Assume losses in suction pipe negligible

$$h_A = z_3 - z_1 + h_f = 300 - 175 + (.02)\frac{1000}{10/12}\frac{(9.74)^2}{64.4}$$

$$h_A = \underline{\underline{161.2}}\ ft$$

$$PWR = \gamma\dot{V}h_A/550 = (62.4)(5.31)(161.2)/550 = 97.1\ HP$$

$$EHP \doteq PWR/\eta_{comb} = 97.1/.65 = 149.4\ HP$$

$$Cost = 149.4\ HP \cdot \frac{.746\ kW}{HP} \cdot \frac{6\ HR}{day} \cdot \frac{30\ day}{mo} \cdot \frac{\$.06}{kW\text{-}h} = \boxed{\$1204/mo}$$

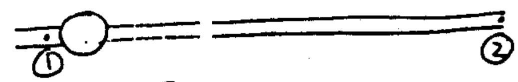
#6] Glycerin at 50°F , μ : .04 lbf-s/ft² S.G = 1.26 > Reference texts
Glycerin at 100°F , μ : .004 lbf-s/ft² S.G = 1.20

$Q = 2500\ \text{gpm} \cdot 1/449 = 5.57\ \text{ft/s}$, $V = Q/A = 5.57/.0884\,\text{ft}^2 = 63.0\ \text{ft/s}$

That velocity is much too high → impossible. Maybe error in problem statement. More realistically lets use 250 gpm.

$Q = 250\ \text{gpm} \cdot 1/449 = .557\ \text{ft}^3/\text{s}$, $V = Q/A = \dfrac{.557\ \text{ft}^3/\text{s}}{.0884\ \text{ft}^2} = \underline{\underline{6.30\ \text{ft/s}}}$

1500 ft 4" Sch 40 - Assume horizontal, neglect minor losses



$$\cancel{\frac{P_1}{\gamma}} + \cancel{\frac{V_1^2}{2g}} + \cancel{z_1} + h_A = \cancel{\frac{P_2}{\gamma}} + \cancel{\frac{V_2^2}{2g}} + \cancel{z_2} + h_f$$

Also Assume $P_1 = P_2$ or Pump is only overcoming friction

$$h_A = h_f = f \frac{L}{D} \frac{V^2}{2g} = (f) \frac{1500}{.3355} \left(\frac{(6.30)^2}{64.4}\right)$$

$h_A : 2756 f$

@ 50° $h_1 = 2756(.49) = \underline{1356\ \text{ft}}$

$P = \dfrac{\gamma Q h}{550} = \dfrac{(1.26)(62.4)(.557)(1356)}{550}$

$P = 108\ \text{HP}$

@ 50°F

$N_R = \dfrac{\rho V D}{\mu} = \dfrac{(1.26)(1.94\ \frac{\text{slug}}{\text{ft}^3})(6.30\ \frac{\text{ft}}{\text{s}})(.3355)}{.04\ \text{lbf-s/ft}^2}$ $\quad \dfrac{1\ \text{lbf}}{1\ \text{slug-ft}/\text{sec}^2}$

$N_R = 130$ laminar

$f = \dfrac{64}{N_R} = \dfrac{64}{130} = \underline{.49}$

For a large pump - combined motor/pump efficiency ≈ 80%

BHP = $108/.8$ = $\boxed{135\ \text{HP Required.}}$

@ 100°F

$h_A : 2756 f = 2756(.052) = 143\ \text{ft}$

$P = \dfrac{(1.20)(62.4)(.557)(143)}{550} = \underline{\underline{11.8\ \text{HP}}}$

For this size pump combined efficiency also ≈ .80

BHP = $10.8/.8$ = $\boxed{13.5\ \text{HP Required}}$

@ 100°F

$N_R = \dfrac{(1.20)(1.94)(6.30)(.3355)}{.004} = 1238$

Still laminar

$f = \dfrac{64}{N_R} = \dfrac{64}{1238} = .052$

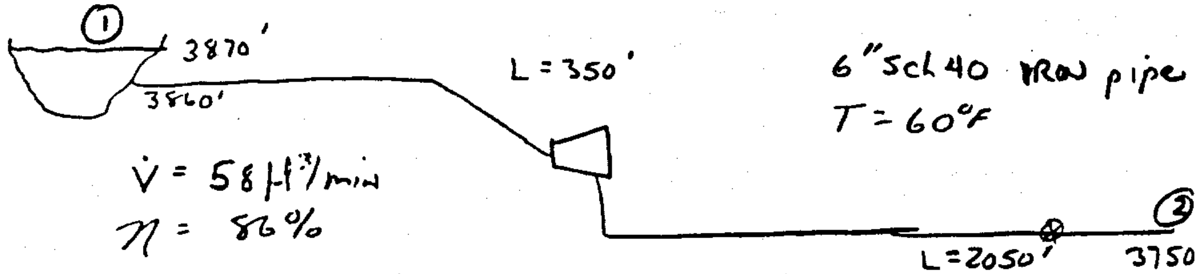
Heat added to achieve 100°F — C_p from Thermo. tables

$Q = \rho Q C_p (T_2 - T_1) = (1.26)(62.4\ \frac{\text{lbm}}{\text{ft}^3})(.557\ \frac{\text{ft}^3}{\text{s}})(.576\ \frac{\text{BTU}}{\text{lbm °F}})(50°\text{F}) = \underline{1261\ \text{BTU/s}}$

$Q = 1261\ \frac{\text{BTU}}{\text{s}} \times \frac{60\ \text{s}}{\text{min}} \cdot .02356\ \frac{\text{HP min}}{\text{BTU}} = \underline{1782\ \text{HP}}$

Then power required for heating & pumping is 13.5 + 1782 = 1795 HP > 135 HP
From strictly an energy point of view don't heat it!
If you include capital costs, the cold fluid will require a pump 10X as large and higher pressure piping: 740 psig compared to 74 psi

7.



6" Sch 40 iron pipe

$T = 60°F$

$\dot{V} = 58\ ft^3/min$

$\eta = 86\%$

minor losses $\left(\frac{L}{D}\right)_e = 815$

a] $h_f = h_{f\,pipe} + h_{f\,minor}$

$V = \frac{\dot{V}}{A} = \frac{58/60}{(.2006)} = \frac{.967}{.2006} = \underline{4.82\ ft/s}$

$h_f = \left[f\frac{L}{D} + f\left(\frac{L}{D}\right)_e \right]\frac{V^2}{2g}$

$N_R = \frac{VD}{\nu} = \frac{(4.82)(.5054)}{1.21\times10^{-5}\ ft^2/s} = 2\times10^5$

$\frac{\epsilon}{D} = \frac{.0005}{.5054} = .001 \longrightarrow f = .02$

$h_f = \left[(.02)\left(\frac{2400}{.5054}\right) + (.02)(815)\right]\frac{4.82^2}{64.4}$

$h_f = [94.8 + 16.3](.361)$

$h_f = (111.1)(.361) = \boxed{40.1\ ft = 40.1\ ft\,lb_f/lb_m}$

b] $\cancel{\frac{P_1}{\gamma}} + \cancel{\frac{V_1^2}{2g}} + z_1 - h_R = \cancel{\frac{P_2}{\gamma}} + \frac{V_2^2}{2g} + z_2 + h_f$

neglect

$h_R = z_1 - z_2 - \frac{V_2^2}{2g} - h_f = (3870-3750) - \cancel{\frac{(4.82)^2}{64.4}} - 40.1$

$\boxed{h_R = \underline{\underline{79.9}}\ ft = 79.9\ ft\cdot lb_f/lb_m}$

c] Power $= \gamma\dot{V}h_R/550 = (62.4)(.967)(79.9)/550 = 8.77\ HP$

$EHP = (Power)\,\eta = (8.77)(.86) = 7.54\ HP$

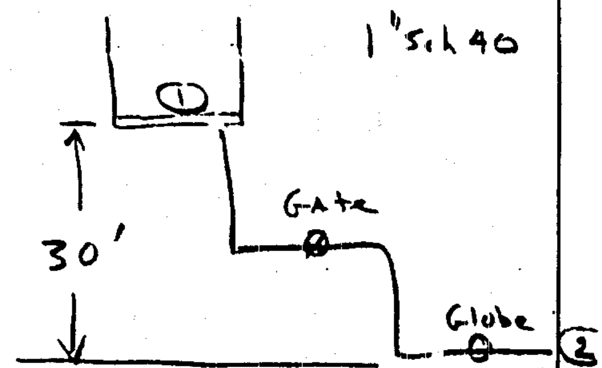
$\#Lights = 7.54\ HP \cdot \frac{746\ W}{HP} \cdot \frac{light}{100\ W} = 56.2 = \boxed{56\ lights}$

1. An existing storage tank is available for use as a feed reservoir for a new process. It is possible to use the old 1 in. Schedule 40 line already in place, provided 25 gpm flow can be obtained. The fluid is linseed oil (viscosity = 15 c.p., specific gravity = 0.92). The tank bottom is 30 ft above the discharge point (open pipe on discharge). The line contains 65 ft. of straight pipe, 3-90° elbows, 1 gate valve and 1 globe valve. Will the existing line be adequate? Assume pipe is wrought iron.

Two possible methods of solutions:

① Solve for the amount of flow that will occur.

② Compare the head loss at 25 gpm to that head available



② $\cancel{\frac{P_1}{\gamma}} + \cancel{\frac{V_1^2}{2g}} + z_1 = \cancel{\frac{P_2}{\gamma}} + \frac{V_2^2}{2g} + z_2 + h_f$

$h_f = z_1 - z_2 - \frac{V_2^2}{2g} = 30 - \frac{V_2^2}{2g}$

$\dot{V} = 25\,\text{gpm} \cdot \frac{1}{449} = .0557\ ft^3/s$

$V = \frac{\dot{V}}{A} = \frac{.0557}{.006} = 9.28\ ft/s$

$h_f = 30 - \frac{9.28^2}{64.4} = \underline{28.7\ ft}$ available to overcome friction

but the actual amount of friction at 25 gpm is

$h_f = h_{f\,pipe} + h_{f\,gl.v} + h_{f\,ga.v} + h_{f\,elb} + h_{f\,ent}$

$= \left[f\frac{65}{.0874} + f(340) + f(13) + 3f(30) + .5\right]\frac{V^2}{2g}$ (Assume ent. loss coef = .5)

$h_f = \left[1187f + .5\right]\frac{V^2}{2g}$

$h_f = \left[1187(.04) + .5\right]\frac{9.28^2}{64.4}$

$h_f = \underline{64.1\ ft}$ required.

$\therefore \boxed{25\ \text{gpm will not flow}}$

If height in tank were 36 ft it would flow

$N_R = \frac{\rho V d}{\mu}$

$\mu = 15\,cp \cdot \frac{lbf\text{-}s/ft^2}{47900\,cp} = .00031\ \frac{lbf\text{-}s}{ft^2}$

$\rho = (.92)(1.94) = 1.785\ slug/ft^3$

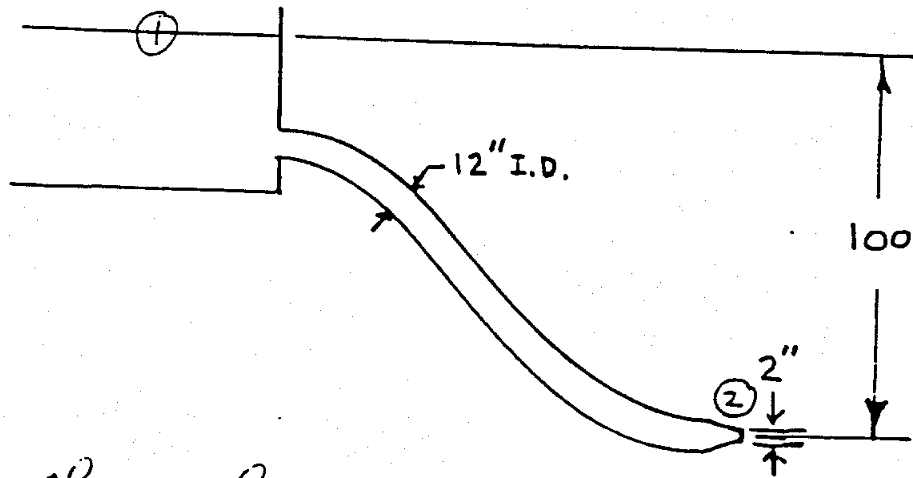
$N_R = \frac{(1.785\ slug/ft^3)(9.28\ ft/s)(.0874\ ft)}{.00031\ lbf\text{-}s/ft^2 \cdot 1\frac{slug \cdot ft}{s^2 \cdot lbf}}$

$N_R = 4670$

$\frac{\epsilon}{D} = \frac{.0002}{.0874} = .0023 \rightarrow f = .04$

9. A cast-iron pipe line, 12 inches inside diameter and 10,000 feet long, leading from a reservoir, terminates in a nozzle of 2-inch diameter, discharging into the atmosphere. The center of this nozzle is 100 feet below the free surface of the water in the reservoir supplying the pipe line.

Find the volume flow rate, cfs, and the power in the jet. Neglect all minor losses.



$$\cancel{\frac{P_1}{\gamma}}^{0} + \cancel{\frac{V_1^2}{2g}}^{0} + z_1 = \cancel{\frac{P_2}{\gamma}}^{0} + \frac{V_2^2}{2g} + z_2 + h_L$$

Get velocity terms on left

$$h_L + \frac{V_2^2}{2g} = z_1 - z_2 = 100$$

$$f\frac{L}{D}\frac{V_p^2}{2g} + \frac{(36V_p)^2}{2g} = 100$$

$$\frac{V_p^2}{2g}\left[f\frac{L}{D} + 1296\right] = 100$$

$$V_p = \sqrt{\frac{64.4\,(100)}{f\left(\frac{10{,}000}{1}\right) + 1296}}$$

$$V_p = \sqrt{\frac{6440}{10{,}000(.0215)+1296}} = \underline{2.06\ ft/s} \rightarrow$$

$$V_p = \sqrt{\frac{6440}{10{,}000(.0205)+1296}} = \underline{2.07\ ft/s}$$

$$Q = A_1V_1 = \left[\pi(1)^2/4\right]\left[2.07\right] = \boxed{1.62\ ft^3/s}$$

$$Pwr\ (JET) = \gamma Q\frac{V_j^2}{2g} = (62.4)(1.62)\frac{(74.5)^2}{64.4} = \frac{8712\ ft\text{-}lb/s}{550} = \boxed{15.8\ HP}$$

$$A_pV_p = A_2V_2$$

$$V_2 = \frac{A_p}{A_2}V_p = \left(\frac{D_p}{D_2}\right)^2 V_p = \left(\frac{12}{2}\right)^2 V_p$$

$$V_2 = 36V_p$$

L = 10,000 ft

D = 1 ft.

Assume $N_R = 10^5$

$$\frac{\epsilon}{D} = \frac{.0008}{1} = .0008 \rightarrow f = .0215$$

$$N_R = \frac{VD}{\nu} = \frac{(2.06)(1)}{1.21\times10^{-5}} = 1.7\times10^5$$

Assume T = 60°F

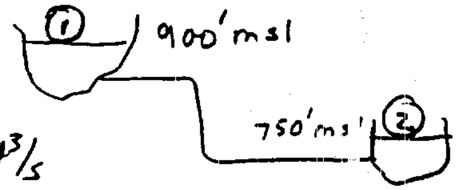
$$\frac{\epsilon}{D} = .0008 \rightarrow f = .0205$$

$$V_j = 36V_p = 36(2.07) = 74.5\ ft/s$$

10. A water line is planned to connect a new reservoir to an existing water treatment plant. The average water surface elevation of the reservoir is 900' msl. The elevation of the inlet works of the treatment plant 7 miles ~~for~~ from the reservoir is 750' msl. It is anticipated that only concrete pipe will be available and that there should be included in the line two (2) gate valves, a check valve and four (4) 90° bends to provide flexible routing. The projected peak day demand is 12 million gallons. Determine pipe size. Concrete pipe is available in 6" increments.

From the energy equation the following equation for pipe size can be derived.

$$f = \frac{\frac{\pi^2 g}{8Q^2}\left(\frac{P_1-P_2}{\gamma}+z_1-z_2+h_A-h_R\right)D_P^4-\sum C_L-\left(\frac{D_P}{D_2}\right)^4+\left(\frac{D_P}{D_1}\right)^4}{\sum\left(\frac{L}{D}\right)_e+\frac{\sum L}{D_P}}$$



for this problem

$$Q = \frac{12\times10^6\,gal}{day}\cdot\frac{1\,day}{24\,hr}\cdot\frac{1\,hr}{60\,m}\cdot\frac{1\,ft^3/s}{441\,gpm} = \underline{18.6\,ft^3/s}$$

$$\frac{P_1-P_2}{\gamma}=0,\quad h_A=h_R=0,\quad z_1-z_2=900-750=150'$$

$$\sum C_L = 0 \;;\; D_1 = D_2 = \infty \;\therefore\; \left(\frac{D_P}{D_2}\right)^2=\left(\frac{D_P}{D_1}\right)^2=0$$

$$\sum\left(\frac{L}{D}\right)_e = \underset{\text{gate Vlv}}{2\times13} + \underset{\text{elbow}}{4\times30} + \underset{\text{Sw. Chk}}{135} = 281 \rightarrow$$ Could be neglected with so much pipe.

$$\sum L = 7\,mi\,(5280) = 36{,}960\,ft$$

Substitution into the equation yields

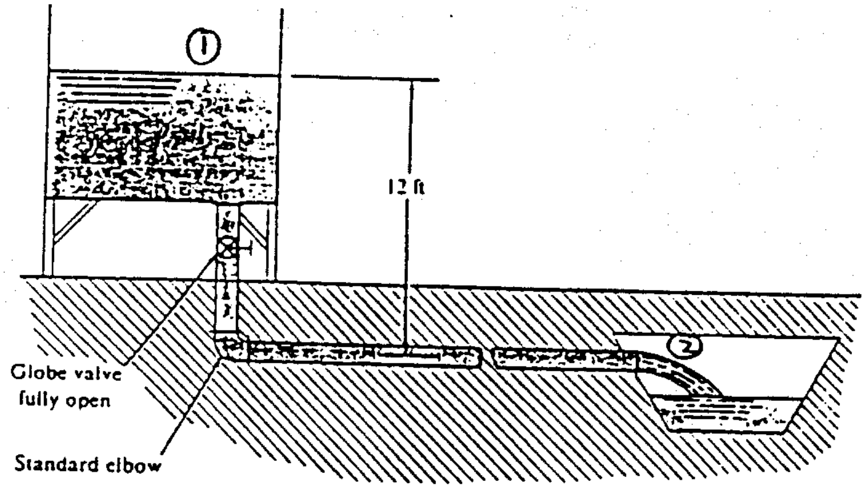
$$f = \frac{\frac{\pi^2(32.2)}{8(18.6)^2}(150)D_P^4-0-0+0}{281+\frac{36960}{D_P}} = \frac{17.2\,D_P^4}{281+\frac{36960}{D_P}}$$

Assume $\epsilon = .004\,ft$ $\quad \frac{\epsilon}{D} = \frac{.004}{D_P}$ $\quad T = 60°F$

$$N_R = \frac{4Q}{\pi D_P \nu} = \frac{4(18.6)}{\pi D_P(1.21\times10^{-5})} = \frac{19.6}{D_P}$$

D_P	f calc	ϵ/D	N_R	f moody	Comment
guess 2.0'	.0177	.002	10^6	.024	fc < fm, goes higher
2.5'	.0415	.0016	8×10^5	.023	fc > fm goes lower. There is no pipe size lower except 2.0' ∴ the smallest pipe size to allow the required flow is $\boxed{2.5'}$

11. The tank shown below is to be drained to a sewer. Determine the size of new Schedule 40 pipe which will carry at least 400 gpm of 80°F water through the system shown. The total length of pipe is 75 ft.



Gen. Eq.

$$f = \frac{\frac{\pi^2 g}{8 Q^2}\left(\frac{P_1-P_2}{\gamma} + z_1 - z_2 + h_A - h_R\right)D_p^4 - \Sigma C_L + \left(\frac{D_p}{D_1}\right)^4 - \left(\frac{D_p}{D_2}\right)^4}{\Sigma \frac{L}{D_p} + \Sigma\left(\frac{L}{D}\right)}$$

Choose ① + ② as shown. $P_1 = P_2 = 0$, $z_1 = 12$, $z_2 = 0$, $h_A = h_R = 0$, $D_1 = \infty$, $D_2 = D_p$

$Q = 400\text{ gpm} \cdot 1/449 = .891\ ft^3/s$, $\Sigma C_L = .5_{entrance}$, $\Sigma L = 75$, $\Sigma\left(\frac{L}{D}\right) = 340_{valve} + 30_{elbow} = 3$

$$f = \frac{\frac{\pi^2(32.2)}{8(.891)^2}\left(0-0+12-0+0-0\right)D_p^4 - 0.5 + 0 - 1}{75/D_p + 370}, \quad \boxed{f = \frac{600 D_p^4 - 1.5}{75/D_p + 370}}$$

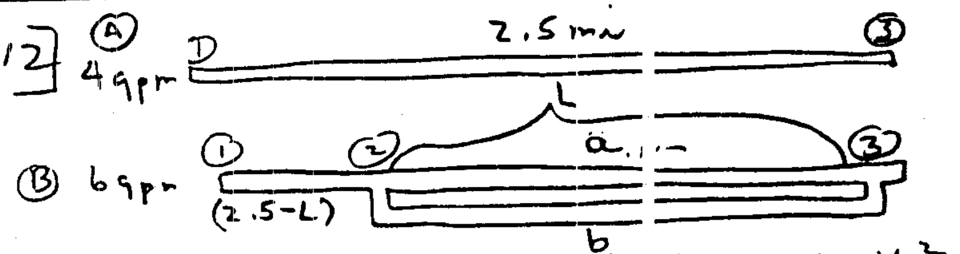
Also, $N_R = \frac{Vd}{\nu} = \frac{4Q}{\pi D \nu} = \frac{4(.891)}{\pi(D)(9.15\times10^{-6})} = \boxed{\frac{1.24\times10^5}{D_p}, \quad D/\epsilon = \frac{D_p}{1.5\times10^{-4}}}$

Guess Sch 40 sizes only

	D_p(ft)	f_{calc}	N_R	D/ϵ	f_{moody}	Comment
6"	(.5054	.0726	2.5×10^5	3370	.0175	Too large
4"	(.3355	.0103	3.7×10^5	2230	.0180	Too Small
5"	(.4206	.0315	2.9×10^5	2810	.0180	Too large.
4.5"	(.374)	.0179	3.3×10^5	2490	.0180	exact size

→ Choose 5" It is the smallest size that is too large. This size will actually allow more flow but valve would be partially closed.

#12]



3" Sch 40

D = .2557 ft

A = .05132 ft²

$\mu = 480$ cp : 2.08×10^{-5}

$\mu = .01$ lb.-s/ft²

$h_{f1\text{-}2} = h_{fa} = h_{fb}$; $f_a \frac{L_a}{D_a} \frac{V_a^2}{2g} = f_b \frac{L_b}{D_b} \frac{V_b^2}{2g}$

$L_a = L_b$, $D_a = D_b$

$\therefore V_a = V_b$ and

$Q_a = Q_b = \frac{1}{2}Q_T = \underline{3\text{gpm}}$

Assume that the increased flow rate will not affect the supply pressure, P_1 or the delivery pressure, P_3, then

h_{fo} = Original friction loss

h_{fwT} = wet-tapped friction loss

$h_{fwT} = h_{f12} + h_{f23}$

(1) $\frac{P_1}{\gamma} + \frac{V^2}{2g} + z_1 = \frac{P_3}{\gamma} + \frac{V_3^2}{2g} + z_3 + h_{fo}$

and

(2) $\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{P_3}{\gamma} + \frac{V_3^2}{2g} + z_3 + h_{fWT}$

subtract (2) from (1) and $h_{fo} = h_{fWT}$ or

$h_{fo} = h_{f12} + h_{f23}$ or

$L_o = 2.5$ mi $= 13{,}200$

L = length of wet tap

$f_o \frac{L_o}{\cancel{D_o}} \frac{V_o^2}{\cancel{2g}} = f_{12} \frac{(L_o - L)}{\cancel{D_{12}}} \frac{V_{12}^2}{\cancel{2g}} + f_{23} \frac{L}{\cancel{D}} \frac{V_{23}^2}{\cancel{2g}}$

$D_o = D_{12} = D_{23}$

Solving for L (algebra)

$V_o = \frac{Q}{A} = \frac{(4)/449}{.05132} = .174$ ft/s

$f_o L_o V_o^2 = f_{12} L_o V_{12}^2 - f_{12} L V_{12}^2 + f_{23} L V_{23}^2$

$V_{12} = \frac{6/449}{.05132} = .260$ ft/s

$L = -\frac{(f_{12}V_{12}^2 - f_o V_o^2) L_o}{f_{12}V_{12}^2 - f_{23}V_{23}^2}$

$V_{23} = \frac{3/449}{.05132} = .13$ ft/s

$L = \frac{[(5.49)(.26)^2 - (8.23)(.174)^2](13{,}200)}{(5.49)(.26)^2 - (10.98)(.13)^2}$

$N_{Ro} = \frac{\rho V D}{\mu} = \frac{(.9)(1.94)(.174)(.2557)}{0.01}$

$N_{Ro} = 7.77$ laminar

$L = 8675\text{ ft} \cdot \frac{1}{5280} = \boxed{1.64 \text{ mi}}$

$f_o = \frac{64}{7.77} = \underline{8.23}$

Added Using Equation (1) $V_1 = V_2$, $z_1 = z_2$

$N_{R12} = 11.66$ laminar

$\frac{P_1 - P_2}{\gamma} = h_{fo}$ or $P_1 - P_2 = \gamma h_{fo} = f_o \frac{L_o}{D_o} \frac{V_o^2}{2g}$

$f_{12} = \frac{64}{11.66} = \underline{5.49}$

$P_1 - P_2 = (.9)(62.4)(8.23)\left(\frac{13200}{.2557}\right) \frac{(.174)^2}{64.4} \cdot \frac{1}{144}$

$N_{R23} = 5.83$ laminar

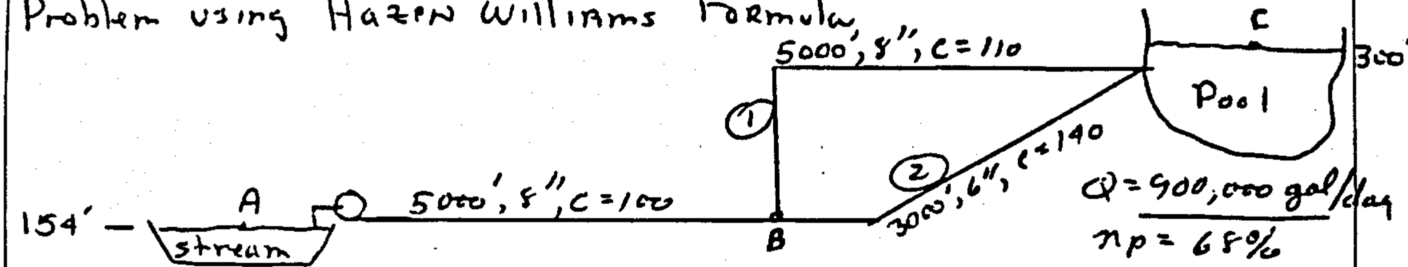
$P_1 - P_2 = \underline{78 \text{ psi}}$

$f_{23} = \frac{64}{5.83} = \underline{10.98}$

If the flow rates had been 40 + 60gpm or 400 and 600gpm, flows would still be laminar and L would still be $\underline{1.64\text{ mi}}$, but $P_1 - P_2$ would be 780 psi and 7800 psi, respectively.

(13)

Problem using Hazen Williams Formula



Find pumping head, W, and HP required.

$$\frac{P_A}{\gamma}+\frac{V_A^2}{2g}+Z_A=\frac{P_C}{\gamma}+\frac{V_C^2}{2g}+Z_C+h_L+W, \quad P_A=P_C=V_A=V_C=0$$

$$W=-(Z_C-Z_A)-h_L=-(300-154)-h_L=\boxed{-146-h_L=W}$$

$$h_L=h_{L\,A-B}+h_{L\,BC}$$

H.W. formula - $Q=0.442\,d^{2.63}C\left(\frac{P_1-P_2}{L}\right)^{.54}$ — P = psi, d = inches, L = feet, Q = gpm

Get equation in terms of h_L, $h_L=\frac{(P_1-P_2)144}{\gamma}$

$$Q=.442\,d^{2.63}C\left(\frac{P_1-P_2}{L}\right)^{.54}\cdot\left(\frac{144/\gamma}{144/\gamma}\right)^{.54}=.442\,d^{2.63}C\left(\frac{144(P_1-P_2)}{\gamma}\right)^{.54}\left(\frac{\gamma}{144L}\right)^{.54}$$

$$\left[\frac{144(P_1-P_2)}{\gamma}\right]^{.54}=h_L^{.54}=\left[\frac{Q}{.442d^{2.63}C}\right]\left[\frac{144L}{\gamma}\right]^{.54}$$

$$\boxed{h_L=\left[\frac{Q}{.442d^{2.63}C}\right]^{1/.54}\left(\frac{144L}{\gamma}\right)} \text{ or } \frac{10.44L\,Q^{1.85}}{C^{1.85}d^{4.8655}}$$

Between A & B $Q = 9000\text{ gal/day}\times\frac{1\text{ day}}{24\text{ hr}}\times\frac{1\text{ hr}}{60\text{ min}}=625\text{ gpm}$

$$h_{L\,A-B}=\left[\frac{625}{.442(8)^{2.63}(100)}\right]^{1/.54}\left(\frac{144\cdot5000}{62.4}\right)=\boxed{62.3\text{ ft}}$$

Between B & C we don't know the flow rate through each leg. but we do know that $h_{L\,B-C}$ is the same for each route)

$$h_{L\,B-C}\,(1)=h_{L\,B-C}\,(2),\quad \left[\frac{Q_1}{.442d_1^{2.63}C_1}\right]^{1/.54}\cancel{\frac{144L_1}{\gamma}}=\left[\frac{Q_2}{.442d_2^{2.63}C_2}\right]^{1/.54}\cancel{\frac{144L_2}{\gamma}}$$

Taking both sides to .54 power

$$\frac{Q_1}{.442(8)^{2.63}(110)}(5000)^{.54}=\frac{Q_2}{.442(6)^{2.63}(140)}(3000)^{.54}$$

$$1.0086\,Q_1=.0109\,Q_2 \quad \text{but } Q_2=625-Q_1$$

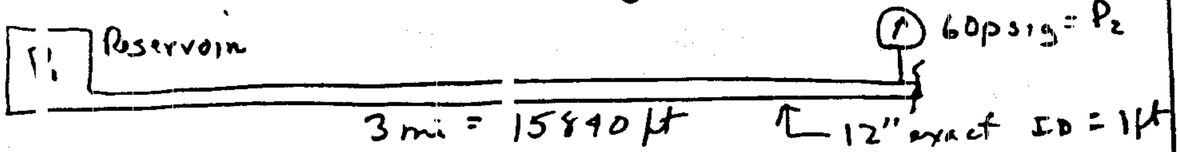
$$.0086Q_1=.0109(625-Q_1)\rightarrow\boxed{Q_1=349\text{ gpm}},\ Q_2=276$$

$$h_{L\,B-C}=\left[\frac{349}{.442(8)^{2.63}(110)}\right]^{1/.54}\frac{144(5000)}{62.4}=\left[\frac{276}{.442(6)^{2.63}(140)}\right]^{1/.54}\frac{144(3000)}{62.4}=17.74\text{ ft}$$

$$W=-146-h_L=-146-h_{L\,AB}-h_{L\,BC}=-146-62.3-17.7=\boxed{-236\text{ ft}}\ W$$

$$HP=\frac{P}{\eta}=\frac{\gamma QW}{550\eta}=\frac{(62.4)\frac{lb}{ft^3}\left(625\frac{gal}{min}\cdot\frac{1\,ft^3/s}{449\,gal/min}\right)\times236\text{ ft}}{550(.68)}=\boxed{54.8\text{ HP}}$$

14] Q = 250 scfs of CH_4 supplying pressure at 60 psig and T = 70°F



Assume incompressible. This is ok if $P_2 > .6 P_1$ - check solution

Assume that $\rho = \rho$ @ 60 psig to start with.

$$\frac{P_1}{\gamma} + \cancel{\frac{V_1^2}{2g}}^{\,0} + \cancel{z_1} = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + \cancel{z_2} + h_f$$

$$P_1 = P_2 + \gamma\left(\frac{V_2^2}{2g} + h_f\right) \text{ but } h_f = f\frac{L}{D}\frac{V_2^2}{2g}$$

$$P_1 = P_2 + \gamma\left(1 + f\frac{L}{D}\right)\frac{V_2^2}{2g}$$

$$P_1 = 60 + \frac{.21}{144}\left(1 + (.0135)\frac{15{,}840}{1}\right)\frac{(62.8)^2}{64.4}$$

P_1 = 79.2 psig + 14.7 = 93.9 psia

Now check is $P_2 > .6 P_1$

use absolute pressures

P_2 = 74.7 psia , $.6P_1 = .6(93.9) = 56.3$

$\therefore$ $P_2 > .6P_1$ - incomp. assumption ok

but standard practice says that if

P_2 is between $.6P_1$ and $.9P_1$ the

average ρ between the two pressures should be used $\therefore$ assume new density at $P = \frac{P_1 + P_2}{2} = \frac{93.9 + 74.7}{2} = 84.3$

then $\rho = \frac{P}{RT} = \frac{(84.3)(144)}{96.4(530)} = .238 = \gamma$

$$V = \frac{10.36}{(.238)(\pi(1)^2/4)} = 55.4 \text{ ft/s}$$

$$P_1 = 60 + \left(\frac{.238}{144}\right)\left(1 + (.0135)\frac{15{,}840}{1}\right)\frac{(55.4)^2}{64.4}$$

$\boxed{P_1 = 76.9 \text{ psig} + 14.7 = 91.6 \text{ psia}}$ another iteration would

Not change P_1 much.

From Thermodynamics

Std. Press = 14.7 psia

Std. Temp = 70°F

$R_{CH_4} = 96.4 \frac{ft\text{-}lbf}{lbm\ °R}$

$P\dot{V} = \dot{m}RT$ or $\dot{m} = \frac{P\dot{V}}{RT}$

$$\dot{m} = \frac{(14.7)(144)(250)}{(96.4)(70+460)} = 10.36 \frac{lbm}{s}$$

$$\rho_{Assm} = \frac{P}{RT} = \frac{(60+14.7)(144)}{(96.4)(530)}$$

$\rho_{Assumed} = .21\ lbm/ft^3$

$\gamma_{Assumed} = .21\ lbf/ft^3$

$$V = \frac{\dot{m}}{\rho A} = \frac{10.36}{(.21)(\pi(1)^2/4)} = 62.8 \text{ ft/s}$$

$\mu = 2.27 \times 10^{-7}$ lbf·s/ft²

$$N_R = \frac{\rho V d}{\mu} = \frac{\left(\frac{.21}{32.2}\right)^{*}(62.8)(1)}{2.27\times10^{-7}}$$

$N_R = 1.8 \times 10^6$

* ρ changed to slug/ft³

Assume steel pipe

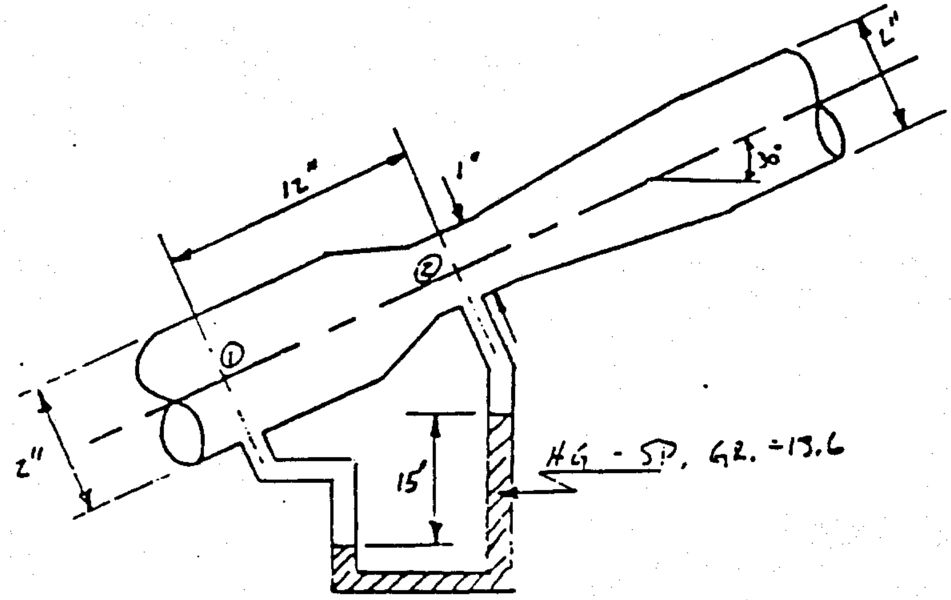
$$\frac{\epsilon}{D} = \frac{.00015}{1} = .00015$$

From Moody $f = .0135$

$$N_R = \frac{\left(\frac{.238}{32.2}\right)(55.4)(1)}{2.27\times10^{-7}} = 1.8\times10^6$$

$\therefore$ f = same = .0135

15. How many gallons per minute (gpm) of gasoline (sp. gr. = 0.80) are flowing through the 2" x 1" venturi meter shown. C_v = 0.97.



$$Q = C_V A_2 \sqrt{\frac{2g\,h_m\left(\frac{\gamma_m}{\gamma}-1\right)}{1-\left(\frac{D_2}{D_1}\right)^4}}$$

$$Q = (.97)\left(\frac{\pi(1)^2}{4(144)}\right)\sqrt{\frac{64.4\left(\frac{15}{12}\right)\left(\frac{13.6(62.4)}{.8(62.4)}-1\right)}{1-\left(\frac{1}{2}\right)^4}} = .196\ ft^3/s \times 449 = \boxed{88\ gpm}$$

This problem was straight forward because Cv was given. In general C_v is not known but must be found from a graph for the venturi meter. C_v is a function of Reynolds Number which contains the flowrate Q, which is what we are looking for. Usually the problem would be worked as follows if Cv were not given: plug in all known values to get

$Q = C_V(.202)$ - Next assume $N_R = 10^5$, go to chart for C_V @ $N_R = 10^5$ and pick value, say $C_V = .98$ Calculate Q

$Q = (.98)(.202) = .198\ ft^3/s$ - Now use this Q to calculate

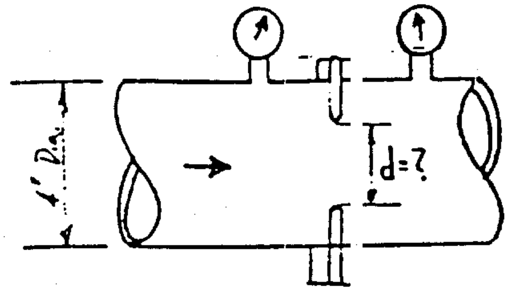
$$N_R = \frac{4\rho Q}{\pi D_1 \mu} = \frac{4(.68)(1.94)(.198)}{\pi\left(\frac{2}{12}\right)(6\times10^{-6})}$$

$N_R = 3.32\times10^5$ - Go this N_R on chart and find $C_V = .97$ + Recalculate Q

$Q = (.97)(.202) = .196\ ft^3/s$

$Q = .196(449) = \boxed{88\ gpm}$

6. A sharp-edged concentric orifice is to be placed between the flanges in a horizontal pipeline to measure the flow; the pressure drop across the orifice is limited to 1% of the static pressure on the line. The pipeline is to carry boiler feedwater that is being pumped into the boiler through a 4-inch. diameter pipe @220°F and 500 psig at the rate of 50,000 lb/hr. Determine the diameter of the orifice, in inches.



$$Q = \frac{\dot m}{\rho} = \frac{50{,}000\ \text{lbm/hr}}{59.8\ \text{lbm/ft}^3}\ \frac{\text{hr}}{3600\ \text{sec}} = \underline{.232\ \text{ft}^3/\text{s}}$$

$D_1 = 4''$, $\Delta P = 1\%$ of 500 psig $= \underline{5\ \text{psi}}$

For an orifice meter:

$$Q = C_o A_o \sqrt{\frac{2g\left(\frac{\Delta P}{\gamma}\right)}{1-\left(\frac{D_o}{D_1}\right)^4}} \quad \text{OR defining} \quad K_o = C_o \Big/ \sqrt{1-\left(\frac{D_o}{D_1}\right)^4}$$

$$Q = K_o A_o \sqrt{2g\left(\frac{\Delta P}{\gamma}\right)} \quad \text{where } K_o = f\left(N_R, \frac{D_o}{D_1}\right) \text{ from graphs}$$

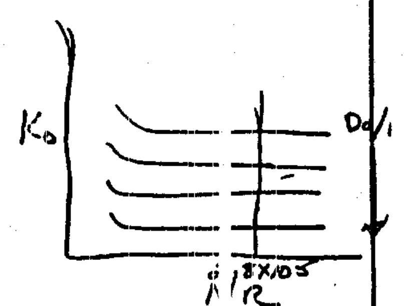
We are looking for D_o since A_o + K_o depend on D_o, solve for $K_o A_o$

$$K_o A_o = Q \Big/ \sqrt{2g\frac{\Delta P}{\gamma}} = .232 \Big/ \sqrt{64.4\left(\frac{5(144)}{59.8}\right)} = .00833$$

$$K_o \frac{\pi D_o^2}{4(144)} = .00833, \quad \underline{K_o D_o^2 = 1.527} \quad \text{where } D_o \text{ is in } \underline{\text{inches}}$$

Use orifice meter graph in CRANES "Flow of Fluids" manual

$$N_R = \frac{4Q}{\pi D_1 \nu} = \frac{4(.232)}{\pi\left(\frac{4}{12}\right)(3.17\times10^{-6})} = 2.8\times10^5$$



Assume D_o: $2''$, $D_o/D_1 = .5$, $K_o(\text{graph}) = .625$

$K_o D_o^2 = (.625)(2)^2 = 2.5 > 1.527$

Assume D_o $1''$, $D_o/D_1 = .25$, $K_o = .600$

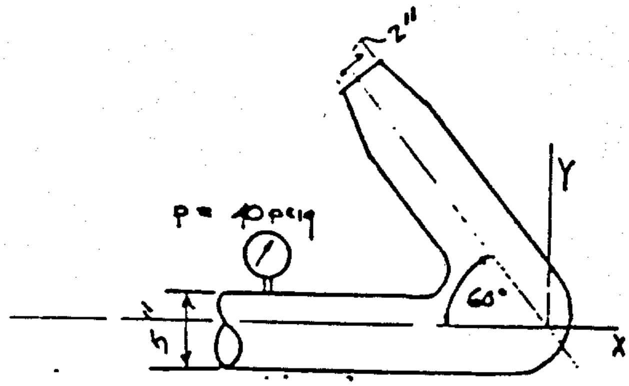
$K_o D_o^2 = (.6)(1)^2 = .6 < 1.527$

Assume $D_o = 1.6''$, $D_o/D_1 = .400$, $K_o = .61$

$K_o D_o^2 = (.61)(1.6)^2 = 1.56 \cong 1.527$

$$\boxed{D_o = 1.6''}$$

17. Water flowing in the bend discharges into the atmosphere through the 2-inch nozzle. The bend lies in a horizontal plane. Determine the resultant of the force the water exerts on the bend. Neglect all losses.



$$F_x = P_1 A_1 \cos\theta_1 - \cancel{P_2}^{\,0} A_2 \cos\theta_2 + \dot{m}(V_1\cos\theta_1 - V_2\cos\theta_2)$$

$$F_y = P_1 A_1 \cancel{\sin\theta_1}^{\,0} - \cancel{P_2}^{\,0} A_2 \sin\theta_2 + \dot{m}(V_1 \cancel{\sin\theta_1}^{\,0} - V_2 \sin\theta_2)$$

$\theta_1 = 0$
$\cos\theta_1 = 1$
$\sin\theta_1 = 0$
$\theta_2 = 120°$
$\cos\theta_2 = -.5$
$\sin\theta_2 = +.866$

$$F_x = P_1 A_1 + \dot{m}(V_1 + .5V_2)$$

$$F_y = -\dot{m}(.866 V_2)$$

$$F_x = (40)\left(\frac{\pi(5)^2}{4}\right) + 3.3(12.5 + (.5)(78.1))$$

$$F_x = \underline{955.1} \text{ lbf}$$

$$F_y = -3.3(.866)(78.1)$$

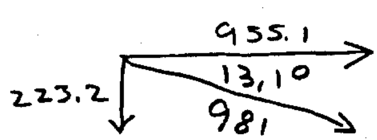
$$F_y = -223.2$$

$$F_R = \sqrt{F_x^2 + F_y^2}$$

$$F_R = \sqrt{(955.1)^2 + (-223.2)^2}$$

$$\boxed{F_R = 981 \text{ lbf}}$$

$$@ \text{ Arc tan } \frac{-223.2}{955.1} = \boxed{-13.1°}$$



$P_1 = 40$ psig

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + \cancel{z_1} = \cancel{\frac{P_2}{\gamma}}^{\,0} + \frac{V_2^2}{2g} + \cancel{z_2} + \cancel{h_L}^{\,0}$$

$$\frac{V_2^2 - V_1^2}{2g} = \frac{P_1}{\gamma}$$

$$A_1V_1 = A_2V_2, \quad V_1 = \frac{A_2}{A_1}V_2 = \left(\frac{D_2}{D_1}\right)^2 V_2$$

$$V_1 = \left(\frac{2}{5}\right)^2 V_2 = \frac{4}{25}V_2$$

$$\frac{V_2^2 - \left(\frac{4}{25}V_2\right)^2}{2g} = \frac{P_1}{\gamma}$$

$$V_2 = \sqrt{\frac{2g\left(\frac{P_1}{\gamma}\right)}{1 - \left(\frac{4}{25}\right)^2}}$$

$$V_2 = \sqrt{\frac{64.4\left(\frac{40(144)}{62.4}\right)}{1 - \frac{16}{625}}} = \underline{78.1 \text{ ft/s}}$$

$$V_1 = \frac{4}{25}(78.1) = \underline{12.5 \text{ ft/s}}$$

$$\dot{m} = \rho A_1 V_1 = (1.94)\left(\frac{\pi(5)^2}{4(144)}\right)(12.5)$$

$$\dot{m} = \underline{3.3} \text{ slug/s}$$

18. A pump is to deliver 350 gpm of hot water. The pump is to receive suction through a 6-inch schedule-40 pipe from a tank elevated above the pump. The water is to be saturated liquid at 250 psig. A net positive suction heat (NPSH) of 75 feet is recommended for these operating conditions. Pipe friction loss will average 1.0 foot for each 20 feet of height.

Determine the minimum water level elevation above the pump centerline to yield the specified NPSH.

$$75 = NPSHR = NPSHA = \cancel{\frac{P_0}{\gamma}} + z_0 - h_L - \cancel{\frac{P_v}{\gamma}}$$

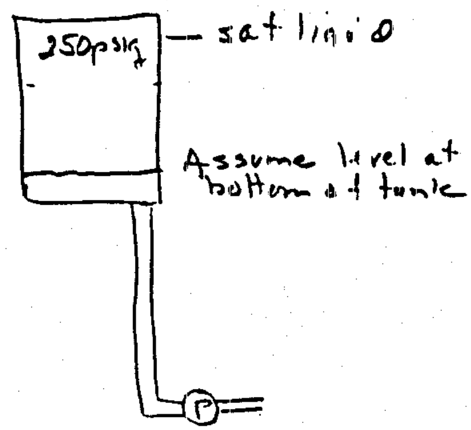
For a saturated liquid $P_0 = P_v$

$$75 = z_0 - h_L$$

but $h_L = \frac{1}{20} z_0$ if water level is at the bottom

$$75 = z_0 - \frac{1}{20} z_0 = \frac{19}{20} z_0$$

$$z_0 = \frac{20}{19}(75) = \boxed{79 \text{ ft}}$$

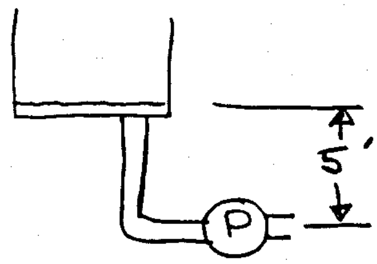


19. A centrifugal pump is to be designed to pump water, at 180°F, at a rate of 200 gpm from a tank which is vented to the atmosphere. The outlet from the tank is located five feet above the pump. The pump suction line is 4" NPS, sch. 40 pipe which is 8 ft. long. This suction line contains 2 short radius 90° elbows. Calculate the net positive suction head that will be available to the pump when the water level is at the point of suction in the tank.

$Q = 200\ \text{gpm} / 449 = \underline{.446\ ft^3/s}$

$T = 180°F$, $\gamma = 60.6\ \frac{lbf}{ft^3}$, $\nu = 3.84 \times 10^{-6}\ \frac{ft^2}{s}$

4" Sch 40, $D = .3355\ ft$, $A = .0884\ ft^2$



$NPSHA = \frac{P_o}{\gamma} + z_o - h_L - \frac{P_v}{\gamma}$

$= \frac{(14.7)(144)}{60.6} + 5 - (.58) - \frac{7.51(144)}{60.6}$ — from Steam tables @ 180°F

$NPSHA = 34.9 + 5 - .58 - 17.84$

$= 21.48 \approx \boxed{21.5\ ft}$

$h_L = h_{L\,pipe} + h_{L\,elbows}$

$h_L = \left(f \frac{L}{D} + f\left(\frac{L}{D}\right)_e\right) \frac{V^2}{2g}$

$V = \frac{Q}{A} = \frac{.446}{.0884} = 5.04$

$N_R = \frac{Vd}{\nu} = \frac{(5.04)(.3355)}{3.84 \times 10^{-6}}$

$N_R = \underline{4.4 \times 10^5}$

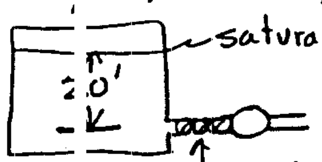
$\frac{\epsilon}{D} = \frac{1.5 \times 10^{-4}}{.3355} = \underline{.0004}$

$f = .0175$

$h_L = \left((.0175)\frac{8}{.3355} + .0175(2 \times 30)\right)\frac{5.04^2}{64.4}$

$= \underline{.58\ ft}$

10] Cent. pump 1200 gpm @ 140 ft head and 1750 rpm.



saturated H_2O at 70 psia

$T_{sat} = 303°F$

$v = .017478$

6" sch 40

$D = .5054$ ft

$A = .2006$ ft^2

80 ft pipe 6" sch 40, 3 elbows, 3 gate valves.

The probable cause is that the net positive suction head available (NPSHA) is less than the NPSH Required at the higher flowrate.

$$NPSHA = h_a + h_s - h_f - h_{vp} = \cancel{\frac{P_a}{\gamma}} + Z - h_f - \cancel{\frac{P_v}{\gamma}}$$

Since the tank contains saturated liquid then $P_a = P_v$

$$NPSHA = 20 - h_f$$

@ 600 gpm

$$NPSHA = 20 - 3.7 = 16.3$$

@ 1200 gpm ::

$$NPSHA = 20 - 14.8 = 5.2$$

For centrifugal pumps including double suction the NPSH required increases with the square of the flowrate or

$$NPSHR_{1200} = \left(\frac{1200}{600}\right)^2 NPSHR_{600}$$

$$NPSHR_{1200} = 4\ NPSHR_{600}$$

Because the pump operates satisfactorily at 600 gpm the NPSHR must be less than 16.3 ft (that which is available) but when the flow rate is increased to 1200 gpm the NPSHR increases enough so that it is more than that available (5.2 ft)

$h_f = h_{f\,pipe} + h_{f\,ent} + h_{f\,el} + h_{f\,vlv}$

Assume square edge entrance

$$h_f = \left[f\frac{L}{D} + C_L + f\left(\frac{L}{D}\right) + f\left(\frac{L}{D}\right)\right]\frac{V^2}{2g}$$

$$h_f = \left[f\frac{80}{.5054} + .5 + 3f(30) + 3f(13)\right]\frac{V^2}{2g}$$

$$h_f = \left[.5 + 287f\right]\frac{(6.66)^2}{64.4}$$

$$V_{600} = \frac{Q}{A} = \frac{600/449}{.2006} = 6.66\ \text{ft/s}$$

$$N_{R_{600}} = \frac{Vd}{\nu} = \frac{(6.66)(.5054)}{.66\times10^{-6}} = 5.6\times10^{5}$$

$$\frac{\epsilon}{D} = \frac{1.5\times10^{-4}}{.5054} = .000297 \quad f \approx .017$$

$$h_f = \left[.5 + 287(.017)\right]\frac{6.66^2}{64.4} = \underline{3.7\ \text{ft}}$$

If flow rate doubles to 1200 gpm
Velocity doubles to 13.32
N_R doubles to 1.1×10^6
f stays about the same .017
h_f quadruples to 14.8

Example. Assume
$NPSHR_{600} = 5$ ft $<$ NPSHA $= 16.3$,
then
$NPSHR_{1200} = 20$ ft $>$ NPSHA $= 5.2$

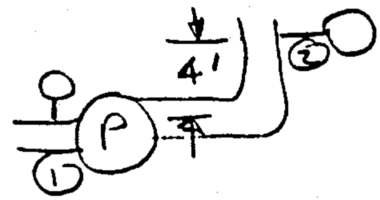
21. A large centrifugal pump has a 10" diameter inlet and a 5" diameter discharge. The measured flow rate is 818 gal./min. The measured inlet pressure is 5" of Hg. above atmospheric and the discharge pressure, measured at a point 4 ft. above the pump inlet, is 30.7 psia. Pump input is 10 horsepower.

Find:
- a. The pump efficiency.
- b. The new flow rate, net head, and BHP if the pump speed is increased from 1750 RPM to 3500 RPM.

$D_1 = 10''$, $A_1 = \frac{\pi(10)^2}{4(144)} = \underline{.545\,ft^2}$

$D_2 = 5''$ $A_2 = \frac{\pi(5)^2}{4(144)} = .136\,ft^2$

$P_1 = 5'' Hg \times \frac{.491\,psi}{1'' Hg} = \underline{\underline{2.46\,psig}}$



30.7 psia
$= \underline{\underline{16\,psig}}$

To get η we need Power delivered to pump which requires h_A.

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 + h_A = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + \cancel{h_L}$$ Neglect h_L in short pipe

$Q = 818\,gpm \cdot \frac{1}{449} = \underline{1.82\,ft^3/s}$

$V_1 = \frac{Q}{A_1} = \frac{1.82}{.545} = \underline{3.34\,ft/s}$ $\quad V_2 = \frac{1.82}{.136} = \underline{13.36\,ft/s}$

$$h_A = \frac{P_2 - P_1}{\gamma} + \frac{V_2^2 - V_1^2}{2g} + z_2 - z_1$$

$$h_A = \frac{(16-2.46)144}{62.4} + \frac{(13.36)^2 - (3.34)^2}{64.4} + 4 = \underline{\underline{37.8\,ft}}$$

$$P_{WR} = \frac{\gamma Q h_A}{550} = \frac{(62.4)(1.82)(37.8)}{550} = 7.81\,HP$$

a) $\eta = \frac{P_{WR}}{BHP} = \frac{7.81}{10} = \boxed{78.1\%}$

b) Affinity Laws

$\frac{Q_2}{Q_1} = \frac{N_2}{N_1}$, $\quad Q_2 = \frac{N_2}{N_1}(Q_1) = \frac{3500}{1750}(1.82) = \boxed{3.64\,ft^3/s \cdot \frac{1}{449} = 1636\,gpm}$

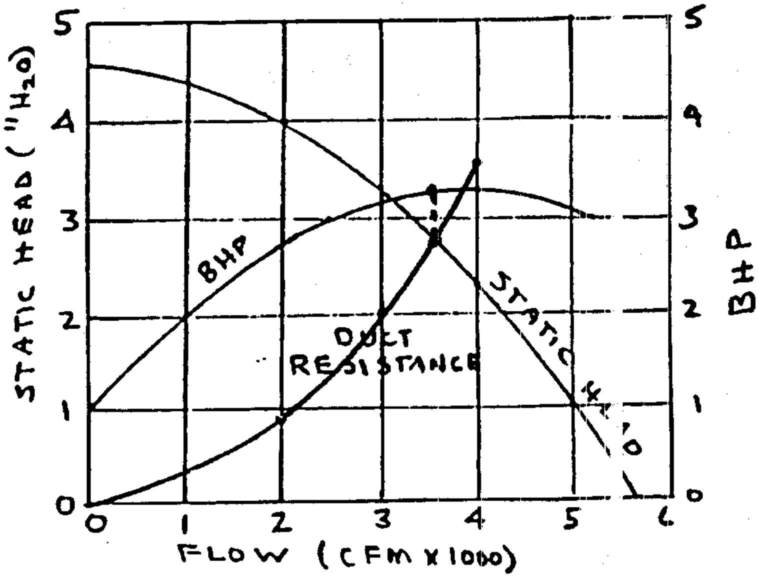
$\frac{H_2}{H_1} = \left(\frac{N_2}{N_1}\right)^2$, $\quad H_2 = \left(\frac{N_2}{N_1}\right)^2 (H_1) = \left(\frac{3500}{1750}\right)^2 (37.8) = \boxed{151.2\,ft}$

$\frac{BHP_2}{BHP_1} = \left(\frac{N_2}{N_1}\right)^3$, $\quad P_2 = \left(\frac{N_2}{N_1}\right)^3 P_1 = \left(\frac{3500}{1750}\right)^3 (10) = \boxed{80\,HP}$

Assumes same efficiency

22] FAN speed $n = 1450$ rpm.
Static resistance of duct is 2.0 in H_2O at 3000 cfm of air

a) Fan curves as shown.
(similar to pump curves)



System curve, generally
$$h_A = h_f = f\frac{L}{D}\frac{V^2}{2g} = K(f)Q^2$$
$K(f)$ = function of friction factor but relatively constant at higher flow rates.

Then:
① $h_{A1} = KQ_1^2$
② $h_{A2} = KQ_2^2$

Dividing ① by ② yields
$$\frac{h_{A1}}{h_{A2}} = \left(\frac{Q_1}{Q_2}\right)^2 \text{ — one of the fan laws}$$

Now get additional points on the duct resistance (system curve) to see where system curve crosses fan curve.

$$h_{A2} = h_{A1}\left(\frac{Q_2}{Q_1}\right)^2 = 2''\left(\frac{2000}{3000}\right)^2 = .89'' \; ; \; h_{A3} = 2''\left(\frac{4000}{3000}\right)^2 = 3.55''$$

Curves cross at $\approx$ $\boxed{\text{3500 rpm and 2.7'' water, BHP = 3.1 HP}}$

b) Desire 5000 cfm at new fan speed

Fan laws (same as pump affinity laws) Assume no change in efficiency of fan unit. Air density is unchanged

$$\frac{Q_2}{Q_1} = \frac{n_2}{n_1}, \quad n_2 = n_1\left(\frac{Q_2}{Q_1}\right) = 1450\left(\frac{5000}{3500}\right) = \boxed{2071 \text{ RPM}}$$

$$\frac{h_{A2}}{h_{A1}} = \left(\frac{n_2}{n_1}\right)^2, \quad h_{A2} = h_{A1}\left(\frac{n_2}{n_1}\right)^2 = 2.7''\left(\frac{2071}{1450}\right)^2 = \boxed{5.50'' \text{ Water}}$$

$$\frac{BHP_2}{BHP_1} = \left(\frac{n_2}{n_1}\right)^3, \quad BHP_2 = BHP_1\left(\frac{n_2}{n_1}\right)^3 = 3.3\left(\frac{2071}{1450}\right)^3 = \boxed{9.62 \text{ HP}}$$